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THE BIENNIAL WIND AND TEMPERATURE OSCILLATIONS OF THE EQUATORIAL STRATOSPHERE AND THEIR POSSIBLE EXTENSION TO HIGHER LATITUDES

J. K. ANGELL and J. KORSHOVER

U.S. Weather Bureau, Washington, D.C.

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ABSTRACT

In equatorial latitudes, during the past decade, a pronounced oscillation in the zonal wind of approximately 26-month period has been noted at pressure surfaces of 25 and 50 mb. The oscillation decreases in amplitude downward and becomes almost undetectable at 100 mb. While this oscillation appears to be in phase at all longitudes, there is an obvious variation in phase with height with the maximum westerly winds occurring about 4 months earlier at 25 mb. than at 50 mb. and 5 to 6 months earlier at 50 mb. than at 100 mb. There is also good evidence for a latitudinal phase lag in the Tropics with the maximum westerly wind at these levels occurring about 6 months earlier at 30° N. than at the equator. There is a suggestion that this approximately biennial oscillation can be traced through the temperate latitudes of the United States and is first to be noted between latitudes 40° and 50° N., from whence the oscillation propagates northward and southward. Near the equator at these levels the biennial temperature maximum occurs about 3 months prior to the biennial west wind maximum, but from 25° to 35° N., at 25 and 50 mb., the maximum temperature is almost exactly out of phase with the maximum west wind, whereas at 100 mb. the two biennial oscillations are nearly in phase.

1. INTRODUCTION

At least during the past decade, a zonal wind oscillation of approximately 26-month period has existed in the equatorial stratosphere such that very close to the equator westerly winds have occurred nearly half the time at pressure surfaces of 50 and 25 mb. and probably at the pressure surface of 10 mb. as well. Thus Viezee [1] found that zonal wind changes of period greater than 1 year were present in the equatorial stratosphere, while McCreary [2], utilizing Christmas Island data, showed that alternating layers of east and west wind moved downward resulting in an annual wind reversal in the lower stratosphere. The same phenomenon may be noted in Christmas Island data presented by Graystone [3]. Ebdon [4] showed that a wind reversal at 50 mb. between January 1957 and January 1958 extended over most equatorial longitudes and pointed out that a wind reversal occurred each January between 1954 and 1959 at Canton Island at 50 mb. In a later paper, Ebdon [5] showed an in-phase relationship between west wind maxima and temperature maxima in equatorial latitudes but was unsuccessful in attempting to relate events in the equatorial stratosphere with events in the equatorial troposphere. Reed et al. [6] gave convincing evidence for the existence of an approximately biennial wind oscillation at widely separated stations in equatorial latitudes and has additional papers in press concerning wind and temperature oscillations in these areas. Ebdon and Veryard [7, 8] discuss in detail the nature of the fluctuations in stratospheric winds which extend from the equator to 30° N. and possibly to 30° S. Finally McCreary [9, 10] has done an excellent job in both collecting and collating data of pertinence to this problem and in providing lucid summaries of the findings. It is

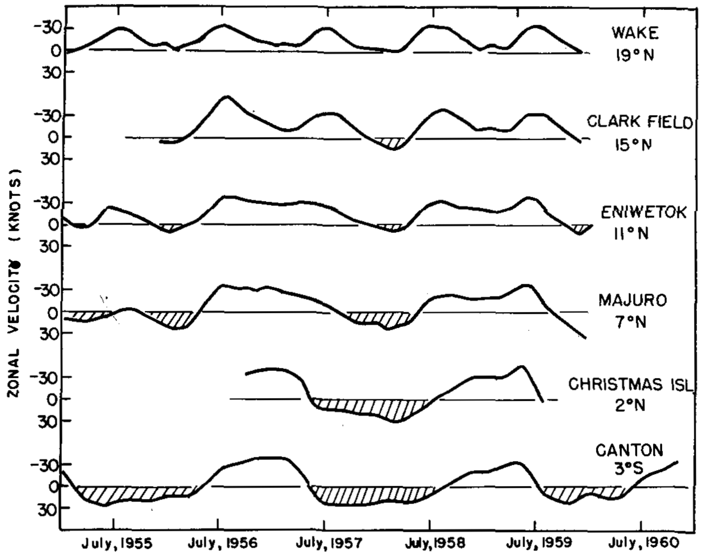

Figure 1.—Variation with time of the mean monthly zonal component at 50 mb. at various latitudes in the western Pacific. The hatched areas indicate westerly winds.

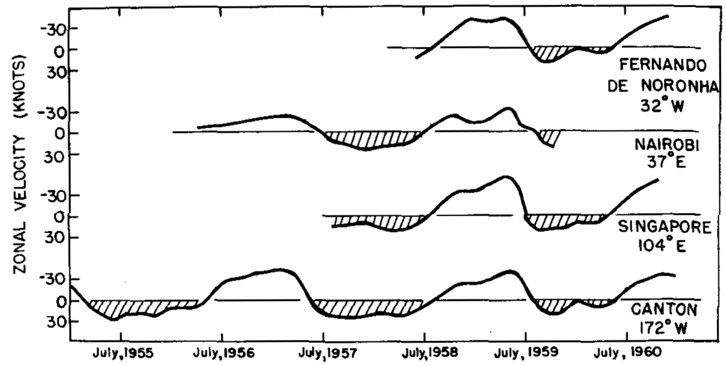

Figure 2.—Variation with time of the mean monthly zonal wind component at 50 mb. for stations located within 4° latitude of the equator and at diverse longitudes. The hatched areas indicate westerly winds.

the purpose of this paper to synthesize these findings and to present evidence that the biennial wind oscillation of the equatorial stratosphere may be traced into temperate latitudes and perhaps even into polar latitudes. It should be emphasized at this point, however, that even though this biennial oscillation has been a prominent feature of the atmosphere during the past decade, this is no guarantee that it will continue to be a prominent feature during the next decade.

2. BIENNIAL WIND REGIME IN THE EQUATORIAL STRATOSPHERE

Figure 1 shows a time trace of the zonal wind component at 50 mb. at various latitudes in the western Pacific. It is apparent that at Canton Island (3° S.) the zonal wind oscillation is predominantly biennial whereas at Wake Island (19° N.) the oscillation is predominantly annual. However, at Canton the asymmetry in the oscillation suggests the influence of the annual regime while at Wake the difference in the strength of the wintertime easterlies suggests the influence of the biennial regime. Between these two extremes, the relative strength of the annual and biennial regimes is a function of proximity to the equator. In the following, for simplicity, the periodicity will often be referred to as biennial even though in actuality it is somewhat longer.

Figure 2 shows a time trace of the zonal wind component at 50 mb. for stations at widely diverse longitudes but within 4° latitude of the equator. It is seen that the oscillation is very nearly in phase at all longitudes; i.e., the mean monthly transition from easterly to westerly wind occurs almost simultaneously regardless of longitude. The existence, at a different longitude, of the same variation in the zonal wind with latitude as noted in figure 1 was confirmed by analysis of U–2 wind data obtained along longitude 65° W. at heights of about 65,000 feet.*

Spectrum analysis of the mean monthly zonal winds permitted the estimation of the period of oscillation. With the length of record available, the spectral analysis was confined to the use of 30 lags, thus yielding variances of the zonal wind at periods of 60 months, 30 months, 20 months, etc. Figure 3 shows the spectra obtained for a sample of stations north and south of the equator and at various longitudes. Obviously, because of the limited amount of data, the resolution at the low frequency end of the spectrum is quite poor. Therefore, the relative magnitudes of the two variances either side of the peak variance were utilized to provide a more exact value for the period of oscillation, as indicated in the figure. The manner in which this was done is best illustrated by examples. Thus, if at periods of 30, 20, and 15 months the respective variances per unit frequency interval (arbitrary units) were 12, 12, and 10, the period of oscillation was set equal to 25 months. If the respective variances were 10, 12, and 10, the period of oscillation was set equal to 20 months. If the respective variances were 10, 12, and 8, the period of oscillation was set equal to 22.5 months; i.e., $25-5(2/4)$, where 2/4 is the ratio of variance differences and 5 is half the time interval between the two maximum variance values. Table 1 shows a listing of the periods so obtained for those stations which exhibited a spectral peak in the neighborhood of 2 years. The average period of oscillation is a shade over 26 months with extremes ranging from 29.2 months at 25 mb. at Eniwetok to 20.4 months at 50 mb. at Fernando de Noronha. Of uncertain significance is the weak tendency for an 8-month periodicity in the wind at stations close to the equator with some suggestion that this period is associated with the annual period farther north and south.

* We are indebted to Major Albert K. Stebbins, III, of the Defense Atomic Support Agency for making these data available.

Table 1.—*Period of oscillation (in months) of mean monthly zonal wind component as derived from spectral analysis. List limited to stations possessing a periodicity near that of the biennial.*

Station	Latitude	Months of data	Period 50 mb.	Period 25 mb.
Johnston Island	17° N.	48	27.0, 11.6	26.9, 11.7
Clark AFB	15° N.	48	27.0, 11.7	25.4, 11.8
Guam	13° N.	48	26.4, 11.5	26.1, 11.7
Eniwetok	11° N.	60	27.4, 11.4	29.2, 11.8
Majuro	7° N.	60	25.6, 10.9	26.2, 7.9
Christmas Island	2° N.	34	28.0, 10.9	27.4, 7.2
Singapore	1° N.	39	22.7, 8.2	----------
Nairobi	1° S.	41	27.4, 8.1	----------
Canton Island	3° S.	66	26.2, 9.1	25.6, 8.9
Fernando de Noronha	4° S.	31	20.4, 7.7	----------

With the length of record available, a 24-month harmonic should give a good representation of the main features of the mean 26-month oscillation under discussion. Accordingly, the second and fourth harmonics of the zonal wind component were obtained for tropical stations utilizing 48 months of data. The triangles, circles, and dots in figure 4 indicate at 25, 50, and 100 mb., respectively, the time of year of maximum west wind (or minimum east wind) at these various stations for both the biennial and annual periods. The vertical lines extending through these points indicate the amplitude of the harmonics. Thus at 25 mb., Canton has a biennial amplitude exceeding 30 kt., whereas the annual amplitude at this pressure surface is on the order of only 5 kt. It is seen that the biennial oscillation at 25 mb. at Canton has the same magnitude as the 100-mb. annual oscillation in the zonal wind at Torishima.

Figure 4 illustrates several interesting features as follows:

(1) The magnitude of the approximately biennial oscillation decreases while passing from 25 mb. to 100 mb. and becomes almost undetectable at the latter level (approximately the tropopause level).

(2) The magnitude of the approximately biennial oscillation decreases to the north and south from the equator and becomes almost undetectable north of 20° N.

(3) There is clear-cut evidence that in the Tropics the west wind maximum at 25 mb. precedes the west wind maximum at 50 mb. by about 4 months, while the west wind maximum at 50 mb. precedes the west wind maximum at 100 mb. by 5 to 6 months. This implies that the biennial wind regime descends at the rate of about 100 feet per day.

(4) There is good evidence that the west wind maximum occurs later at the equator than at 20° or 30° N., with the lag between equator and 30° N. on the order of 6 months. This implies that (at least in the Northern Hemisphere) the biennial wind regime moves toward the equator at the rate of about 10 miles per day.

3. EXTENSION OF THE BIENNIAL WIND REGIME TO TEMPERATE AND POLAR LATITUDES

One of the most interesting and original features to be noted from figure 4 is the tendency for the biennial oscillation to appear earlier at more northerly latitudes and the

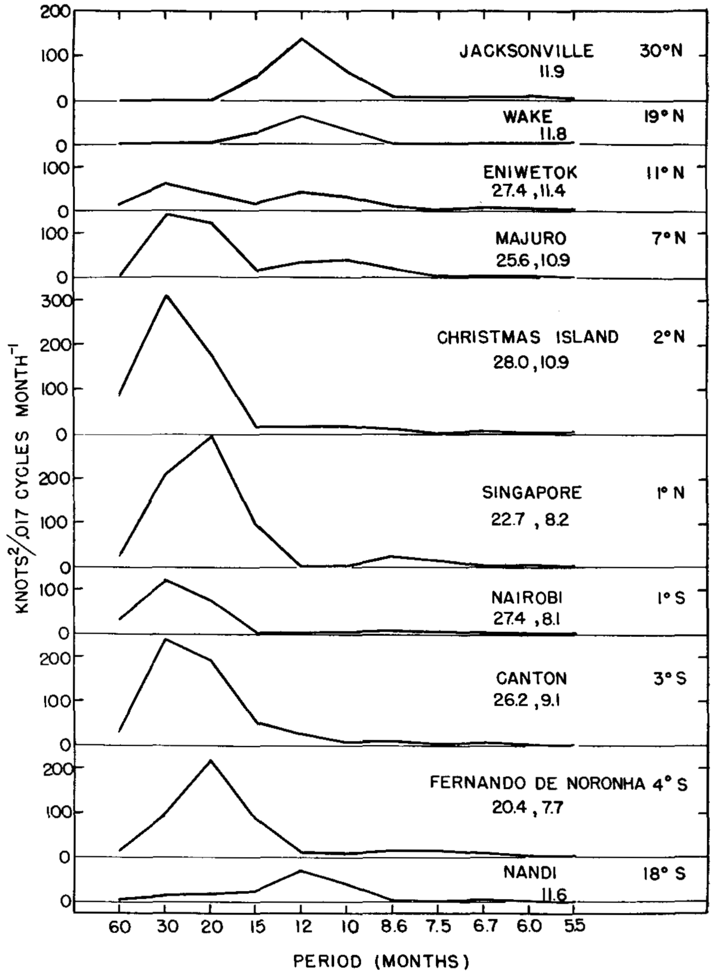

Figure 3.—Variance per unit frequency interval of the mean monthly zonal wind component at 50 mb. at selected stations varying in latitude and longitude. The numerals indicate the number of months at which the variance is a maximum, obtained using a weighting technique (see text).

suggestion that, although very weak, the approximately biennial oscillation can be traced into temperate latitudes. In an attempt to confirm this tendency, a harmonic analysis of the zonal wind was performed for many stations between the latitudes from 20° N. to 83° N., and the results are presented in figure 5. In temperate latitudes great difficulties are introduced through loss of observations at high levels, especially during the winter months. In addition, though it would be highly desirable to utilize more than 4 years of data in order to investigate a phenomenon of approximately 2-year period, this appears almost impossible at the present time because of the limited heights attained by rawinsondes prior to 1956. With a realization of these difficulties, and the consequent uncertainties inherent in the harmonic analysis, one can see from figure 5 some tendency for a bunching of the time of maximum westerly winds around July 1957 at 30° N., around January 1957 at 40° N. and 50° N., and again around July 1957 at 60° and 70° N. It must be realized,

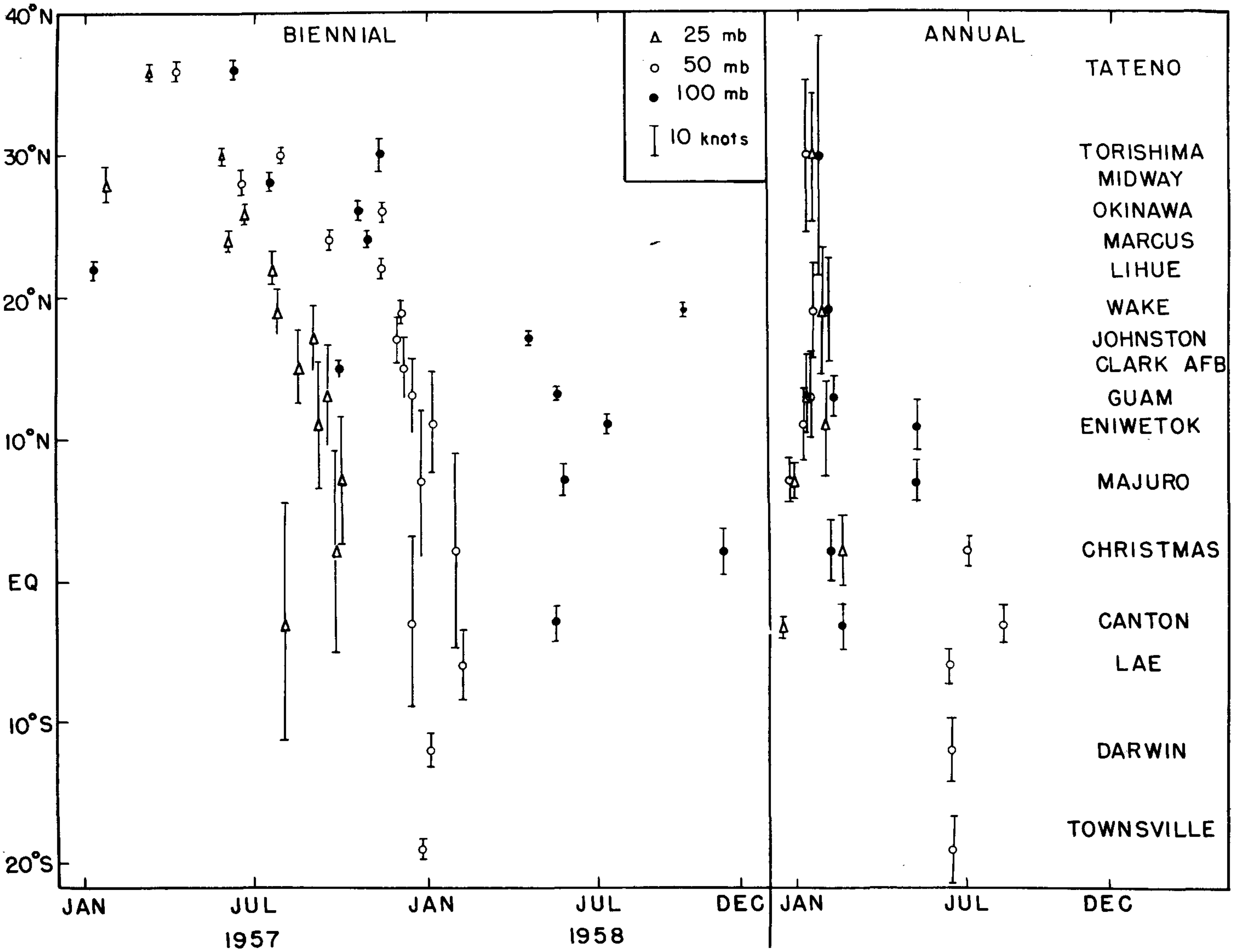

Figure 4.—Variation with latitude and height of biennial and annual harmonic phases and amplitudes in tropical regions. The triangles, circles, and dots indicate the time of maximum west wind (or minimum east wind) at 25, 50, and 100 mb. respectively. The vertical bar through these points indicates the amplitude of the appropriate harmonic, with the scale given in the small block.

however, that a certain subjectivity enters into the placement of the times of maximum. Thus with data initiating in January 1956, a phase angle of 15° could mean that the maximum west wind occurs either on February 15 in 1956 or on February 15 in 1958 and when one is trying to establish phase trends with latitude, as we are doing here, this can lead to uncertainties.

In summary of figure 5 we would then state the following:

(1) There is at least a suggestion that the biennial wind regime noted in the equatorial stratosphere can be traced with much reduced amplitude across the United States with the maximum west wind occurring about 1 year earlier at 40° to 50° N. than at the equator. There is even weaker evidence that the biennial regime can be traced still farther north with the oscillation occurring later at polar latitudes than at temperate latitudes. This suggests a temperate latitude origin for the approximately biennial oscillation, although one might well wonder why the oscillation would appear so much weaker at the suggested latitude of inception than in equatorial latitudes. This may not be an impossible situation, however. Thus, to take a familiar example, is it possible that the increase in tropopause height as one approaches the equator produces the same effect on the biennial oscillation as a shelving beach does on an approaching wave?

(2) Contrary to equatorial findings, in temperate and polar latitudes the biennial oscillations tend to be of larger amplitude at 100 and 200 mb. (the latter included where this pressure surface should be well within the stratosphere) than at 25 and 50 mb. In particular, at least over the United States and Canada, a strong biennial oscilla-

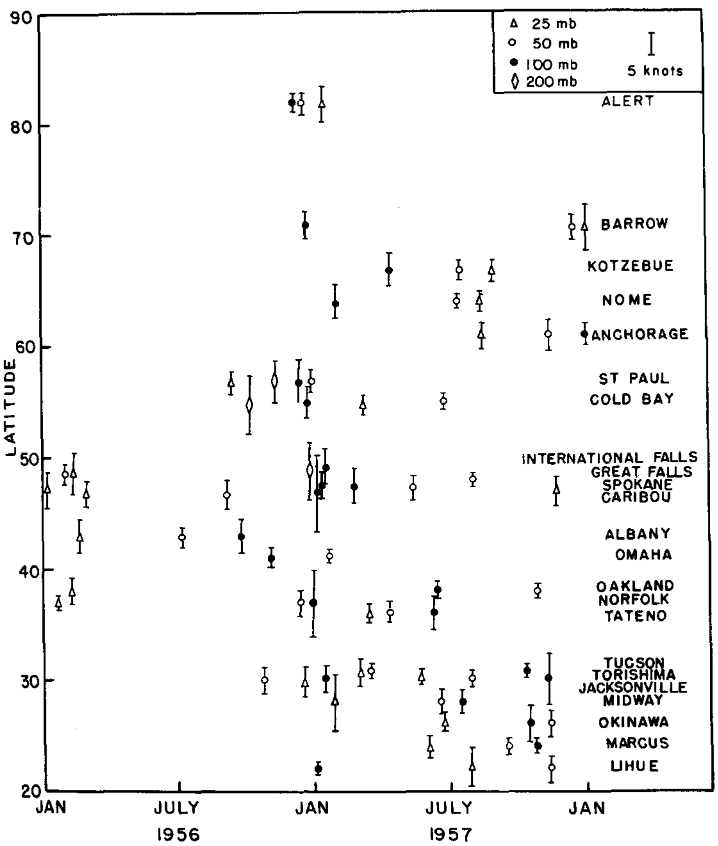

FIGURE 5.—Variation with latitude and height of biennial harmonic phase and amplitude in temperate and polar regions. Otherwise, please see legend for figure 4.

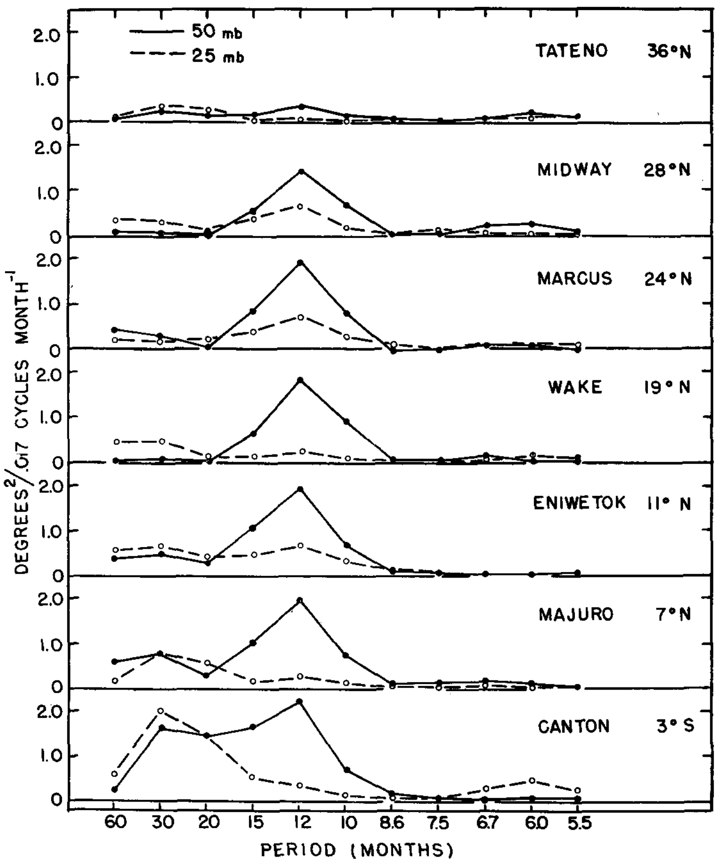

FIGURE 6.—Variance per unit frequency interval of the mean monthly temperature at 50 mb. (solid lines) and 25 mb. (dashed lines) at various latitudes.

tion exists at these lower levels yielding a consistent tendency for maximum westerly winds to occur in January 1957.

(3) In temperate latitudes the biennial oscillation at 25 mb. appears isolated from the oscillations at 50, 100, and 200 mb., with the 25-mb. oscillation almost exactly 180° out of phase with the others.

4. BIENNIAL TEMPERATURE OSCILLATION IN THE EQUATORIAL STRATOSPHERE

In equatorial latitudes the biennial temperature oscillation is not as pronounced as the biennial wind oscillation, as can be seen by reference to the spectral analysis of temperatures in figure 6. Also in the case of temperature, the oscillation is most apparent at 25 mb. (it is practically undetectable at 100 mb.) but mainly because of a sharp decrease in intensity of the annual temperature oscillation while passing from 50 to 25 mb. rather than because of an increase in the intensity of the biennial oscillation between these two levels. Poleward of 10° N. the biennial temperature oscillation is not really represented by a peak in the spectral analysis except for the suggestion that a true peak is again observed at Tateno at 36° N.

Cross spectrum analysis performed on the wind and temperature yielded the phase lag between maximum

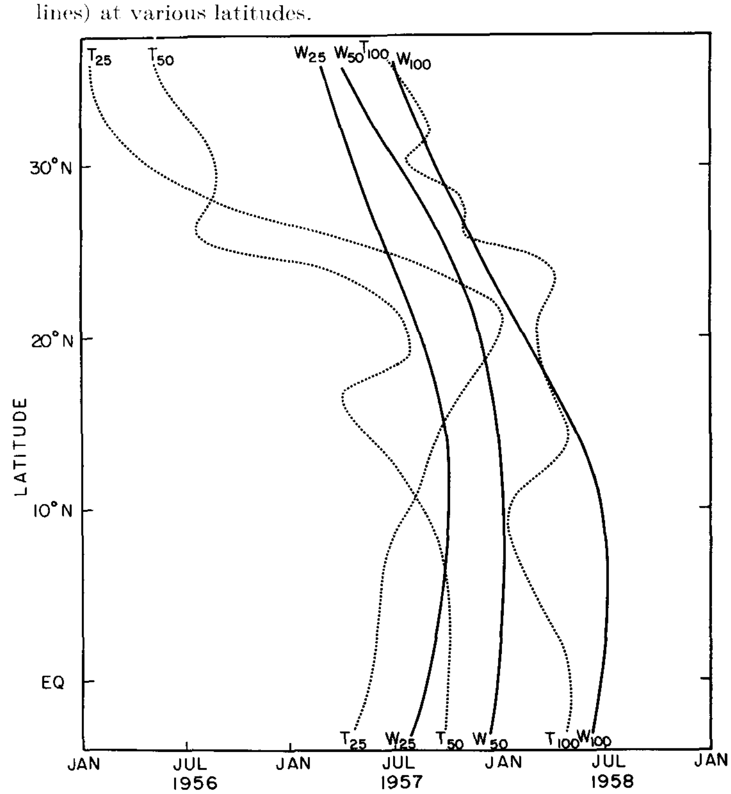

FIGURE 7.—Smoothed time of biennial west wind maxima (solid lines) at 25, 50, and 100 mb. and time of temperature maxima at the three levels (dashed lines) deduced from cross-spectrum analysis of wind and temperature.

wind and maximum temperature and from this the time of maximum temperature was determined. Spot checks showed that the time of maximum temperature determined in this way agreed with the time of maximum temperature determined by harmonic analysis; rather surprising in view of the weakness of the biennial temperature oscillation. Figure 7 shows the time of temperature maximum at the three levels of 100, 50, and 25 mb. (dashed lines) as determined from the phase difference with the smoothed time of west wind maximum (solid lines). Within 10° latitude of the equator the temperature maximum consistently occurs about 3 months prior to the west wind maximum. Farther north, at 100 mb., the time of maximum temperature tends to coincide with the time of maximum west wind, whereas at 25 and 50 mb., after some chaotic wanderings, the temperature maximum tends to be almost exactly 180° out of phase with the west wind maximum. Note that neither the biennial wind nor biennial temperature oscillations presented here appears to relate in an obvious manner with the anomalous polar stratospheric warming which occurred early in 1957. With regard to the dubious accuracy of temperature measurements at these great heights, it should be emphasized that we are dealing here with a biennial oscillation and while there might be some reason to suspect an annual or semiannual temperature variation due to different radiative influences on the radiosonde, it is hard to imagine why a biennial variation could be due to this effect.

5. CONCLUSION

This preliminary description of the approximately biennial wind regime in the stratosphere has produced more questions than it has answered. It is apparent that work must continue concerning the reality of the biennial oscillation in the temperate and polar stratosphere and with extension to tropospheric levels. At least in the troposphere many years of good wind data would be available. Also it is natural that the data be considered from the point of view of the anomalous stratospheric warming of early 1957 and from the point of view of solar phenomena in general. Certainly pronounced non-annual or non-diurnal oscillations in geophysics are sufficiently rare that every effort should be made to come to grips with the problem and to solve it. With the multitude of groups presently working on the biennial wind oscillation, it is probable that a rational explanation of the phenomenon will soon be forthcoming.

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